(*Paper No. 3747.*)

"Survey for Port Elizabeth Water-Supply."[1]

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The history of the water-supply for Port Elizabeth affords an interesting example of the difficulties and uncertainties to be met with when designing water-supplies for young colonial towns, especially those situated in districts where there is no hydrographical information available. In April, 1820, the population of the settlement in Algoa Bay, now known as Port Elizabeth, consisted of only thirty-five persons including the garrison. According to the census of 1875 there were at that time 13,049 inhabitants; and in 1891 the number had risen to 23,266 inhabitants, of whom 13,297 were whites. In December, 1901, there were about 37,000 inhabitants, including 19,000 whites, and growing suburbs were in existence outside the municipal limits.

The town of Port Elizabeth was originally built on a narrow strip of land along the sea-shore, at the foot of a very steep hill, and the business portion is still practically confined to the two streets parallel with the shore. The residential portion, however, gradually extended up this hill (over 300 feet high) and along the comparatively level ground at the top.

The original water-supply was brought from Shark's River—a little stream about 1½ mile to the south of the town; but the collecting reservoir, which was some 60 feet above the sea, could only deliver water to the lower part of the town. As late as 1876 the upper portion of the hill was supplied almost entirely from rain-water collected in tanks on the roofs of the houses, and the supply was consequently small and precarious. The lower part of the town drew its supply partly from shallow wells fed by surface drainage, and partly from small springs in the hill-side, the remainder coming from Shark's River; the water in the first was certified by Dr. Dunstable, as early as 1864, to be "exceedingly impure," and the

[1] A description of the completed scheme, together with a map of the district is given in Mr. Ingham's Paper, "Port Elizabeth Water-Supply," *post*, p. 347.

springs were unreliable; the Shark's River supply was notoriously bad, containing salts of magnesia in such quantities that ships' captains objected to watering in Algoa Bay.

In 1876 the late Mr. J. G. Gamble, M. Inst. C.E., hydraulic engineer to the Cape Government, was asked to report on a water-supply; but beyond knowing that the mean rainfall in Port Elizabeth for 13 years was 24·36 inches, he had practically no data on which to base his recommendation. Mr. Gamble recommended that the supply should be brought from Van Staaden's, and the construction of the works was described by him in a Paper read before The Institution.[1] These works, consisting of a small intake-basin, a pipe-line about 27 miles long and a service-reservoir, were completed in 1879.

The Van Staaden's River is a mountain stream rising in a region subject to heavy rainfalls and long periods of drought, and the great differences in the recording gauges can be easily understood. The discharge is also affected by the condition of the surface-vegetation, as veld-burning has a marked effect in decreasing the replenishment of springs and in increasing the flood-discharge. Under such circumstances a few irregular gaugings give a very poor indication of the daily amount available; in fact, within 4 years of the construction of the pipe-line from the Van Staaden's intake the inhabitants of Port Elizabeth were agitating for a storage-reservoir. This was eventually sanctioned, and during 1891–92 a dam to conserve about 30 million gallons was built just above the old intake, the engineer being Mr. Thomas Stewart, M. Inst. C.E. Even this addition, on account of the decreasing yield of the springs, proved insufficient for the increasing demand, and in 1897–98 a pumping plant was erected about 2 miles further down the gorge, and in such a position as to pump into the original main. The average daily consumption during November, 1898, was 631,633 gallons, rising in the last week to a daily consumption of 709,428 gallons. In December, 1898, there was only 8 days' supply in the Van Staaden's reservoir, and the service-reservoir was practically empty. Assuming the population to have been 40,000, the daily average per head for the month was 16 gallons—a very small amount for such a town, as although Port Elizabeth had then no sewage system it was the universal practice to water private gardens from the town-supply.

Although the pumping plant had been erected in 1898 the question of the water-supply continued to be very acute, and in 1899

[1] "The Waterworks of Port Elizabeth, South Africa," Minutes of Proceedings Inst. C.E., vol. lxxiv, p. 128.

a Committee consisting of Messrs. T. M. McEwen and G. W. Smith, Assoc. MM. Inst. C.E., and the Author was appointed by the Town Council to report on the best source for a supplementary water-supply that would yield at least another 1,000,000 gallons per diem.

The Committee, after careful investigation, recommended the Elands River basin as the most suitable district from which the required supply could be obtained. This is situated on the north side of the range of mountains in which the Van Staaden's River takes its rise, the latter flowing from north to south, and the Elands River flowing from west to east. Throughout its length the course of the Elands River lies parallel with this range, and there is a succession of small spruits and streams flowing into it from the mountains, the three largest being the Bulk, Sand and Palmiet Rivers, the last being a tributary of the Sand River.

The Bulk River is about 30 miles from Port Elizabeth; and a careful gauging taken at the foot of a waterfall of considerable height gave a flow of 487,000 gallons in 24 hours. About 7 miles further along the slope of the mountain is the junction of the Sand and Palmiet Rivers; and here the gauging showed 974,000 gallons a day.

The combined flow of the three streams thus exceeded the minimum required by the Town Council, and the supply could be delivered into the existing town-main at a point 13½ miles from Port Elizabeth. The Committee, therefore, after receiving a satisfactory analysis of the water, recommended that a preliminary survey should be made. They also urged that a regular series of gaugings should be taken over a prolonged period, so as to have a reliable record of any fluctuations in the discharges. Though there were no rainfall-records for the catchment-areas of these three rivers, the gaugings mentioned were obtained during a period of extreme drought; and as all the farmers in the district were unanimous in characterizing the season as exceptionally severe, the Committee felt justified in thinking that the flow in ordinary seasons would be in excess of the amount required. The Town Council decided to act on the recommendation, and in 1900 the Author was seconded from the Public Works Department to make the preliminary survey.

About 13½ miles from Port Elizabeth, at a place named Green Bushes, there is a break-pressure tank (727·4 feet above sea-level) on the original main from the Van Staaden's reservoir, and as that was designed to carry about 1,000,000 gallons a day, it was decided to make this point the junction with the new pipe-line; leaving the question of increasing the capacity of the pipes between Green Bushes and Port Elizabeth to be dealt with in the future.

The first commanding point was $6\frac{1}{2}$ miles from Green Bushes, at the foot of a spur jutting out from the range of hills referred to. Beyond mile 7 there were several high ridges or spurs running at right angles to the direction of the survey; the most important were those near miles $8\frac{1}{2}$, 10, 12 and 14, and there were still higher ridges near and beyond mile $15\frac{1}{2}$. The direction selected was now purely a matter of judgment, and the method of surveying followed was to set up a level, direct it towards the next high ridge, and then select some point slightly higher than the axis of the instrument. This ensured that the tops of the ridges were all crossed on an ascending gradient, and that, as the survey was run up the valley, they would more or less approximate to a possible hydraulic gradient. The ridges near miles $15\frac{1}{2}$, $17\frac{1}{2}$ and $19\frac{1}{2}$ were all apparently too high to be crossed by the pipe-line; but as the position of the intakes had not been definitely selected, it was decided to run the survey over them, so as to keep to the shortest possible line, and avoid the steep and broken ground that would be encountered in making a detour. While this trial-line was being run, levels were taken along the highest ridges, and the survey was extended up and down the ravines, so as to ascertain the best places for crossing with the actual pipe-line. A suitable site was selected for the intake just below the junction of the Sand and Palmiet Rivers, which was 233 feet above, and $24\frac{1}{2}$ miles from, the break-pressure tank at Green Bushes.

The longitudinal section of the preliminary survey showed that the line crossed three ridges, each of them higher than the intake; but that with three short tunnels very satisfactory hydraulic gradients could be arranged, the pipes crossing at or above the summits of all other ridges. The Author considered that the preliminary line gave sufficient information on which to base a provisional estimate, and the cost of the three tunnels was therefore included, as the question of a cheaper line could be investigated later.

The top of the Bulk River waterfall was approximately the same level as the selected intake on the Sand River, but as the latter was the larger source of supply, the survey for it was completed first. The nearest point to the former was selected for the junction, the distance away being about 2 miles, and the difference in level being 38 feet. Gauges were placed on the three streams, and during the short time that elapsed before the preliminary survey was completed, it was found that the minimum flow of the Bulk River was 163,536 gallons per day, and of the Sand and Palmiet Rivers 551,664 gallons per day, with a maximum flow of over 1,000,000 gallons per day. But the Town Council was warned that gaugings extending over so short a time should be accepted with the greatest caution, and they were urged to continue systematic gaugings. This they decided to do, and it was afterwards found that the minimum flow available was much less than the figures given above; in fact, storage proved to be an essential feature of the scheme.

Final Location of Pipe-Line.—When selecting the final scheme it became necessary to decide if the tunnels should be omitted, and the line taken round the spurs. There were three courses open:—

(1) To retain the tunnels.
(2) To take the pipe-line round the spurs over a succession of deep precipitous ravines.
(3) To take the pipe-line along the river-valley.

The last two involved an increase of length; with the addition that in No. 2 the line would be over extremely rough and broken ground, while in No. 3 much heavier pipes would be involved due to the increased head. Further, the Elands River is subject to serious floods, during which it might be impracticable to repair damages to the pipes. For these reasons the Author decided to keep out of the river-valley as much as possible, and to locate the line as near the hydraulic gradient as the ridges would allow. This gave the shortest possible line, required the minimum weight of metal in the pipes, and for 20 miles enabled the pipe-line to be kept away from the river; for the first 5 miles it was impossible to do this on account of a high ridge to the south. The point at which the pipe-line was designed to leave the valley is 199 feet below the intake-level at the Sand River.

The question of whether to adopt the three-tunnel line or to take it round the spurs was not definitely settled by the Author, as the date for lodging the Parliamentary plans did not allow sufficient time for making the necessary surveys. The limits of deviation, however, were extended in order to include sufficient ground for making the change, should it be found advisable.

The river-crossings were through swamps largely composed of reeds and "palmiets" (*Prionium palmita*), and it was proposed to lay the pipes through these. There was no indication of erosion found in any part of the swamps, and moreover as the palmiets were generally about 5 feet high, and were interlaced into a dense mass, there appeared to be no danger from floods. To ascertain whether these palmiets contained any acid that would be detrimental to the pipes some plants were submitted to a chemical test; acid was reported to exist, but in such minute quantities that it might be disregarded. The design for these crossings provided that the pipes should receive a coating of some bituminous compound before being embedded in broken stone or concrete, and as an additional protection, an increased thickness of metal was allowed.

Pipes.—The design provided for the use of mild-steel pipes on the ground of their being cheaper than cast-iron; wagon-transport alone would have cost many thousands of pounds more for cast-iron than for steel pipes, and the cost of handling and the loss from breakage would have been very much greater. From a minimum of $\frac{1}{8}$ inch the thickness of metal was increased to suit the pressure at various places.

The number and sharpness of the curves, formed by the surface of the ground, necessitated particular attention being paid to the bends. By using Stewart-Lloyd inserted joints, giving a clearance of $\frac{3}{8}$ inch at 3 inches from the base of the socket, 16-foot pipes can be laid to a radius of 256 feet, and 8-foot pipes to a radius of 128 feet, with a minimum $\frac{3}{16}$-inch thickness of lead in the joints. Pipes can also be laid to short radii by using Kimberley collars placed tangentially to the angle of deflection, and by specifying for slightly larger diameters than are required for straight joints. Sections to a large natural scale were made of the tops of the ridges, of the bottoms of the ravines and of all very broken ground; on these the vertical curves of the pipe-line were plotted, and special bends were only designed where the minimum radius could not be used.

Hydraulic Gradient.—The hydraulic gradient was calculated by taking the actual length of the pipes and allowing for the loss of head at bends (using Weisbach's formula). The gradients were not intended to be finally fixed, as the whole question could be dealt with when the Council decided to undertake the construction.

Reservoirs and Dams.

When the preliminary report was made the only information regarding the flow of the Bulk, Sand and Palmiet Rivers was the result of 62 days' gaugings: this showed a minimum of 720,000 gallons in one day and a maximum extending into several million gallons. The gaugings were continued, and at the time of the final report, they had extended over 490 days.

During 1900, after 2 years' drought, the following results were obtained:—

Sand River,	330 days gave a daily average of . . .	440,000	gallons.
Palmiet	,, ,, ,, ,, ,, ,, ,, ,, . . .	283,000	,,
		723,000	,,
Bulk River,	302 days gave a daily average of . . .	271,000	,,
	Total ,, ,, ,, . .	994,000	,,

During 1901, up to the 9th June, the results were:—

Sand River, Palmiet River,	160 days gave a daily average of over	991,000	gallons.
Bulk River,	160 ,, ,, ,, ,, ,, ,, ,,	426,000	,,
	Total ,, ,, ,, ,,	1,417,000	,,

Between the 1st January and the 4th February, 1901, the daily average of the Sand and Palmiet Rivers, combined, was as low as 538,000 gallons a day; but during the 7 days from the 14th to the 20th February the total gaugings amounted to over 9,738,000 gallons, and between the 18th and the 24th March to over 17,457,000 gallons. The Bulk River discharge, on the 30th January and the 4th February, fell as low as 95,000 gallons; while between the 18th and 24th March the total gaugings were 7,805,000 gallons, and on the 20th April over 3,400,000 gallons.[1] The averages shown could only be obtained in practice by constructing reservoirs to equalize the supply and demand; and the storage-capacity required was ascertained by compiling a table, in which the daily discharges of the Sand and Palmiet Rivers, between the 13th February and the 9th June, were credited to the reservoir, and from which 1,000,000 gallons a day were deducted. At the end of that time there would have been in hand over 19,000,000 gallons, which, used to supplement a daily flow of 722,000 gallons (the average for 1900), would be sufficient to supply Port Elizabeth with 1,000,000 gallons a day for 70 days.

A similar table was compiled for the Bulk River, using the gaugings between the 18th March and the 9th June, and deducting 400,000 gallons a day. At the end of the period there would have been over 15,000,000 gallons in the reservoir, which, added to the daily flow of 271,000, would represent a supply of 400,000 gallons a day for 120 days.

On the foregoing basis, even in very dry weather, the town could rely on 1,400,000 gallons a day for at least 70 days, before having to

[1] As the gauges were not large enough to measure the maximum flow, the correct figures are higher.

depend solely on the daily flow of the rivers. During normal seasons the storage would probably never be exhausted, and the ordinary flow would be sufficient for all requirements. As the discharges were greater than those actually gauged, the Author felt justified in advising the Town Council to make provision for drawing 500,000 gallons a day from the Bulk River, and 1,100,000 gallons a day from the Sand and Palmiet Rivers. The design of the dams provided for a storage-capacity of 25,000,000 gallons at the Bulk River, and 19,000,000 gallons at the junction of the Sand and Palmiet Rivers. A larger storage-capacity was proposed for the Bulk River on account of the great irregularity in its daily flow, and also because provision was made to draw off 400,000 gallons a day instead of 271,000 gallons—the daily average for 1900.

As both reservoirs were situated in ravines, the dams were designed for the surplus water to flow over their crests. Hydrographical observations in South Africa were almost unknown, and there was no information available regarding the discharge, so that the overflow-capacity of the weir became a matter of judgment. According to Fanning's formula, $Q = 200\ M^{\frac{5}{6}}$ (where Q denotes the discharge in cubic feet per second, and M denotes the drainage-area in square miles), the discharge of the Sand and Palmiet catchment-areas as scaled from the maps would be 2,026 cubic feet per second, and from the Bulk River 1,271 cubic feet per second. Burton however says that for Japan twice Fanning's discharge should be allowed, and as very severe rain-storms take place in Cape Colony[1] ample allowance was made. The waste-weir crest of the Sand River dam was designed to be 135 feet long, and that of the Bulk River dam 105 feet long; with the water 5 feet deep the discharges (Francis's formula, $Q=3\cdot012\ l H^{1\cdot53}$, where l denotes the clear length of overfall and H denotes the depth of water in feet) would be 4,770 and 3,710 cubic feet per second respectively. The Bulk River was allowed a greater comparative discharge than the Sand and Palmiet Rivers on account of its being in a much narrower ravine; the latter reservoir would hold an extra 2,300,000 cubic feet before the level rose 5 feet above the crest, while in the former the extra capacity would only amount to about 1,000,000 cubic feet, and the flood-level would consequently rise more rapidly.

It may seem extraordinary that no provision was made for compensation-water; the practice, however, has not yet been introduced

[1] 9·40 inches in 15½ hours have been recorded in Port Alfred; and 10·20 inches in 21 hours have been recorded in the Transvaal.

into South Africa, and where rights are affected it is the custom to pay compensation in money. Several farmers used the water from the three rivers for irrigation purposes, and as some of them would undoubtedly be affected, the Author recommended purchase of their land by the Board. The lower riparian interests were amply protected as the Private Bill included arbitration- and compensation-clauses.

The Author was assisted by Messrs. J. H. McKenzie and J. D. Fettes, Assoc. MM. Inst. C.E., to whom great credit is due for the accuracy of the levels; in spite of the mountainous nature of the country the levels checked to within 3 inches throughout the route.